LOW TEMPERATURE EVALUATION
OF THE
HTANFET SILICON-ON-INSULATOR (SOI)
N-CHANNEL FIELD EFFECT TRANSISTOR

Test Report

Richard Patterson
NASA Glenn Research Center
&
Scott Gerber
ZIN Technologies
&
Ahmad Hammoud
QSS Group, Inc.

NASA Glenn Research Center
Cleveland, Ohio

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Background

NASA is presently developing Silicon-On-Insulator (SOI) devices for use in harsh environments including high levels of radiation and extreme temperature. New SOI application-specific integrated circuits (ASIC) with high reliability constitute a key element in meeting NASA requirements. Such circuits include static random access memory and arithmetic function chips. SOI devices are typically designed for use in high temperature applications. Little is known, however, about their performance in low temperature environments. The objective of this work was to evaluate SOI devices in the temperature range of 20 °C to -190 °C. Due to delays in obtaining samples of the NASA GSFC/JPL developed SOI ASIC devices, Honeywell SOI power FET devices were acquired for low temperature evaluation.

The Honeywell HTANFET is a high temperature N-channel power FET fabricated using SOI processes [1]. Its operating temperature is specified in the range of -55 °C to +225 °C and is a member of Honeywell's high temperature product line. As part of this work, a control device (a standard "non-SOI" power FET) was also subjected to the same low temperature testing and its results were used for comparison to the SOI device. The control device selected for this purpose was an International Rectifier IRFD110 HEXFET Power MOSFET. Table I shows some of the operating specifications for the HTANFET and IRFD110 devices tested.

Table I. Manufacturer's specifications of devices tested [1-2].

Device	Symbol	Parameter	Rating	Units
HTANFET	$T_{(oper)}$	Operating temperature	–55 to +225	°C
	I_D	Continuous drain current	* 1 max	A
	$V_{(BR)DSS}$	Drain-source breakdown voltage	* 90 min	V
	$R_{DS(on)}$	Drain-to-source on-state resistance, V_{GS}=5V & I_D=0.1A	* 0.4 typ	Ω
	$V_{GS\ (th)}$	Gate threshold voltage, I_D = 100μA	* 1.6 typ * 2.4 max	V
	$V_{GS\ (max)}$	Maximum gate-to-source voltage	10	V
IRFD110	$T_{(oper)}$	Operating temperature	–55 to +175	°C
	I_D	Continuous drain current	* 1 max	A
	$V_{(BR)DSS}$	Drain-source breakdown voltage	* 100 min	V
	$R_{DS(on)}$	Drain-to-source on-state resistance, V_{GS}=10V & I_D=0.6A	* 0.54 max	Ω
	$V_{GS\ (th)}$	Gate threshold voltage, I_D = 250μA	* 2.0 min * 4.0 max	V
	$V_{GS\ (max)}$	Maximum gate-to-source voltage	20	V

* operating condition T = 25 °C.

Test Setup

One HTANFET device and two IRFD110 devices were characterized in the temperature range of +20 °C to -190 °C. Performance characterization was obtained in terms of their gate threshold voltage ($V_{GS(th)}$), drain-to-source on-state resistance ($R_{DS(on)}$), and drain current (I_D) versus drain-to-source voltage (V_{DS}) family curves at various gate voltages (V_{GS}). These properties were obtained using a digital curve tracer. The devices were characterized at test temperatures of 20 °C, -50 °C, -75 °C, -100 °C, -125 °C, -150 °C, -175 °C, and -190 °C. Limited thermal cycling testing was also performed on the devices. These tests consisted of subjecting the devices to a total of five thermal cycles between +20 °C and -190 °C. A temperature rate of change of 10 °C/min and a soak time at the test temperature of 10 minutes were used throughout this work.

Results and Discussion

The two devices of the IRFD110 tested have shown exact behavior in their characteristics with temperature. Data pertaining to only one of these devices will, therefore, be presented for comparison purposes with the HTANFET SOI MOSFET. Figure 1 shows the gate threshold voltage ($V_{GS(th)}$) versus temperature for the IRFD110 and the HTANFET devices. The gate threshold voltage for each device was measured at very small values of drain currents. A drain current of 250µA and 100µA was set for the IRFD110 and the HTANFET, respectively, according to their manufacturer's specifications. Either value of drain current could have been used due to the very small variation in measured gate threshold voltage with such small values of drain current. As seen from Figure 1, both devices exhibit an increase in gate threshold voltage with decreasing temperature. The IRFD110, which has a maximum specified gate voltage of 20V, exhibits a gate threshold voltage in the range of 3.03V to 3.92V from 20 °C to -190 °C. This corresponds to a normalized gate threshold voltage ($V_{GS(th)}/ V_{GS\,(max)}$) between 0.152 and 0.196. The HTANFET, which has a maximum specified gate voltage of 10V, displays a gate threshold voltage in the range of 1.64V to 2.21V from 20 °C to -190 °C. This corresponds to a normalized gate threshold voltage range of 0.164 to 0.221. In general, both devices show comparable changes in gate threshold voltage with change in temperature.

Figure 2 shows the drain-to-source on-state resistance ($R_{DS(on)}$) versus temperature for the two devices. On-state resistance values were obtained at a drain current of 0.6A and a gate voltage of 8V for the IRFD110, and at a drain current of 0.6A and a gate voltage of 5V for the HTANFET. As can be seen from Figure 2, both devices exhibit a decrease in on-state resistance with decreasing temperature down to - 175 °C. Beyond this temperature, the on-state resistance for both devices, however, begins to increase as temperature is decreased further. At any given temperature, the HTANFET has a slightly higher on-state resistance than the IRFD110.

Figure 3 shows the output characteristics of the IRFD110 MOSFET at room temperature (20 °C). The output characteristics are depicted as drain current (I_D) versus drain-to-source voltage (V_{DS}) family curves at various gate voltages (V_{GS}). The range of the gate voltage utilized was from 3.0V to 8.0V. Note that no output is obtained with V_{GS} equal to 3.0V, which is below the gate threshold voltage of 3.03 volts. Figure 4 shows the output characteristics of the same device at -190 °C. Two temperature-induced effects can be noted in the output characteristics of the device with change in the test temperature. The first is the downward shift of the V_{GS} curves due to the increase in the gate threshold voltage with decreasing temperature. This trend is more obvious as illustrated in Figures 3 and 4 for V_{GS} = 5.0V or less. There is also a leftward shift of the V_{GS} curves, especially at $V_{GS} \geq 6.0$V. This shift is primarily due to the decrease in the on-state resistance with decreasing temperature.

The output characteristics of the HTANFET SOI MOSFET at room temperature are shown in Figure 5. Gate voltages (V_{GS}) utilized in this test were between 1.5V and 6.0V. Once again, a V_{GS} level exceeding the gate threshold voltage value must be applied for the device to produce any output. Figure 6 shows the output characteristics of the same device at -190 °C. Similar to its IRFD110 counterpart, the HTANFET device exhibits changes in its output characteristics with temperature. These changes, which are reflected by the shift and steepness of the family curves, are attributed to the increase in the gate threshold voltage and the decrease in the on-state resistance as temperature is decreased.

The effects of thermal cycling on the devices are shown in Figures 7 through 10 for the two devices. The output characteristics of the IRFD110 before thermal cycling and after 5 thermal cycles are shown in Figures 7 and 8, respectively. Those for the HTANFET device under the same conditions are shown in Figures 9 and 10. It appears that, for either type of device, no changes occur in the operational behavior due to this thermal cycle activity. For example, the pre- and post-cycling values of both the gate threshold voltage and the on-state resistance of the two devices remain almost the same as shown in Table II.

Conclusion

An SOI HTANFET device and two IRFD110 devices were characterized in terms of their output characteristics for potential use at low temperatures. The properties investigated included gate threshold voltage ($V_{GS(th)}$), drain-to-source on-state resistance ($R_{DS(on)}$), and drain current (I_D) versus drain-to-source voltage (V_{DS}) family curves at various gate voltages (V_{GS}). The devices were evaluated in the temperature range of +20 °C to -190 °C. Thermal cycle testing was also performed in this temperature range. The preliminary results indicate that the temperature-induced changes were similar for both, the SOI and the non-SOI, devices and were transitory in nature. Some of the effects caused by the low temperature exposure were an increase in the gate threshold voltage, a decrease in the on-state resistance, and a shift in the I_D - V_{DS} characteristic curves of the devices. Thermal cycling was found to produce no changes in the characteristics of the devices as both experience full recovery. Further comprehensive testing is, however, required for a complete assessment of the performance and stability of these devices. Suitability and reliability of these and other devices for specific applications need to be determined under long-term exposure as well as multi-stress conditions.

References

1.HTANFET HIGH TEMPERATURE N-CHANNEL POWER FET Data Sheet, Honeywell.
2. IRFD110 HEXFET POWER MOSFET Data Sheet, International Rectifier.

Acknowledgments

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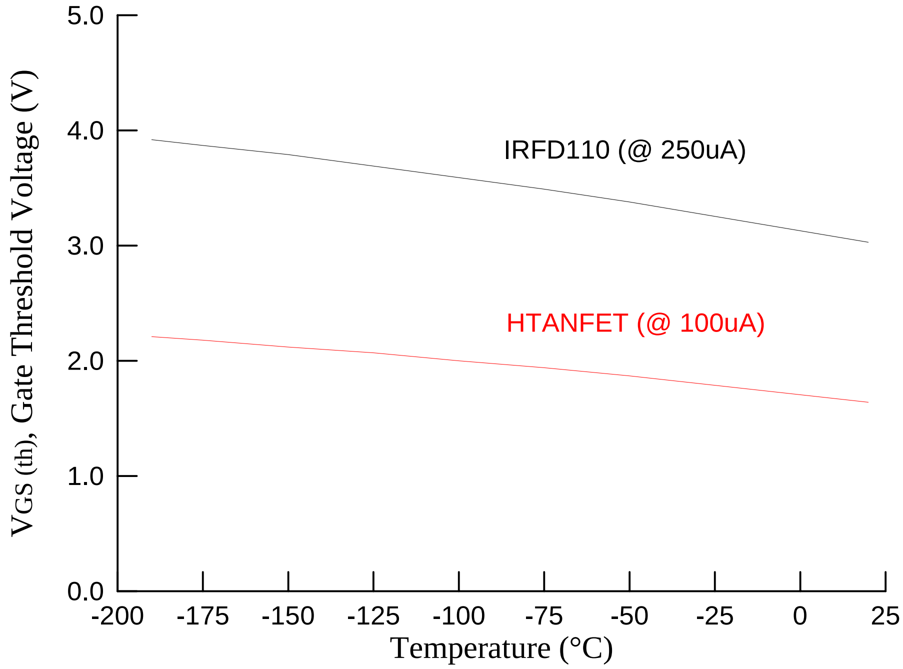
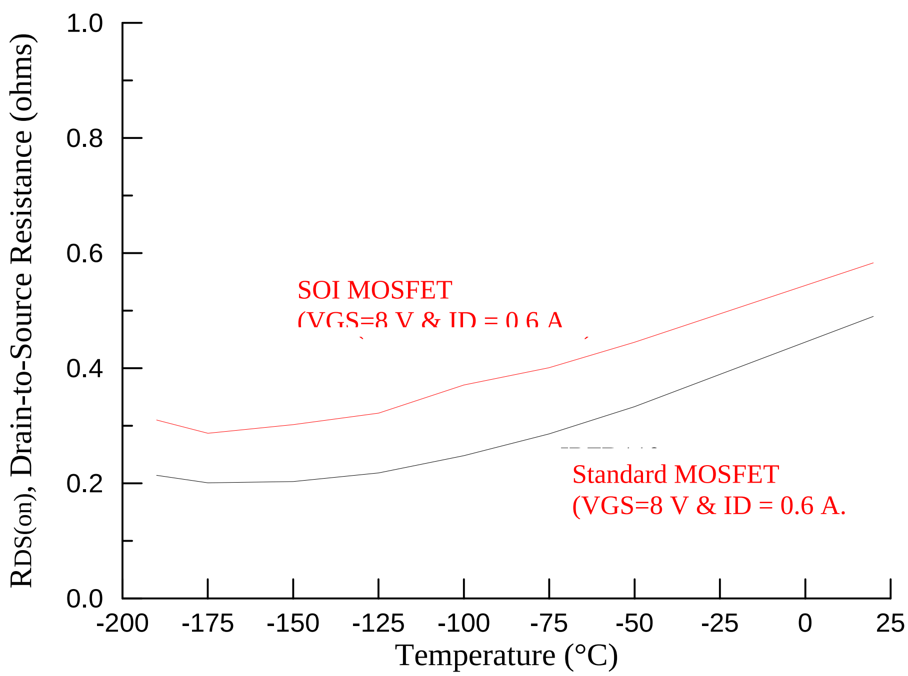


Figure 1. Gate Threshold Voltage for the HTANFET and the IRFD110 devices versus temperature.



RDS(on), Drain-to-Source Resistance (ohms)
1.0
0.8
0.6
0.4
0.2
0.0
-200
-175
-150
-125
-100
-75
-50
-25
0
25
Temperature (°C)
SOI MOSFET
(VGS=8 V & ID = 0.6 A
Standard MOSFET
(VGS=8 V & ID = 0.6 A.

Figure 2. Drain-to-Source Resistance for the HTANFET and the IRFD110 devices versus temperature.

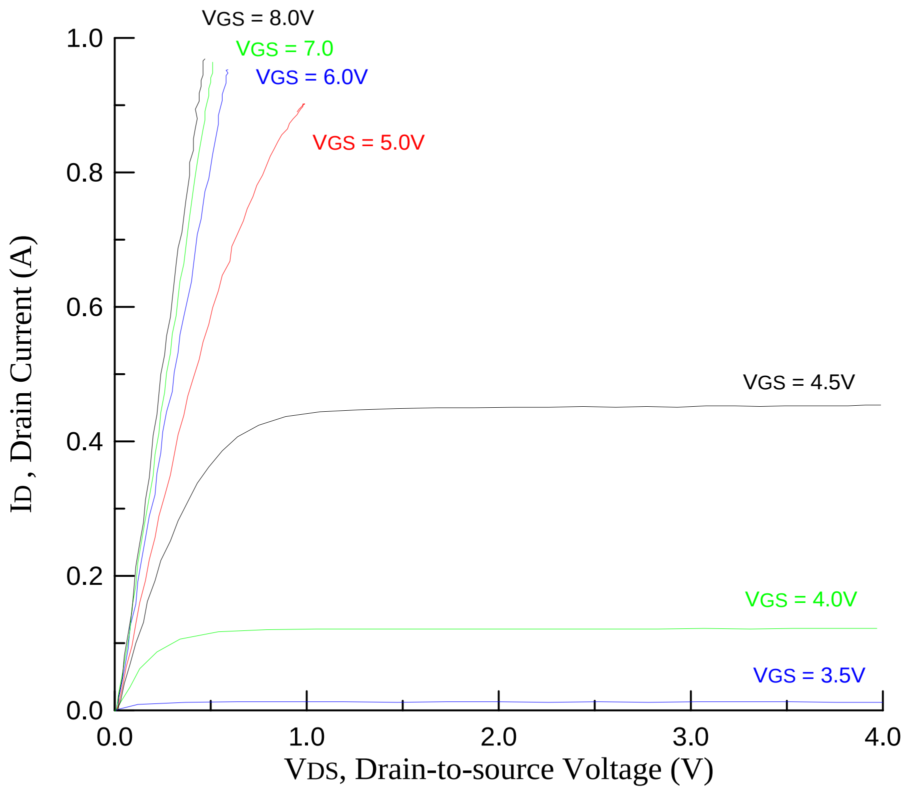


Figure 3. Output characteristics of the IRFD110 device at 20 °C.

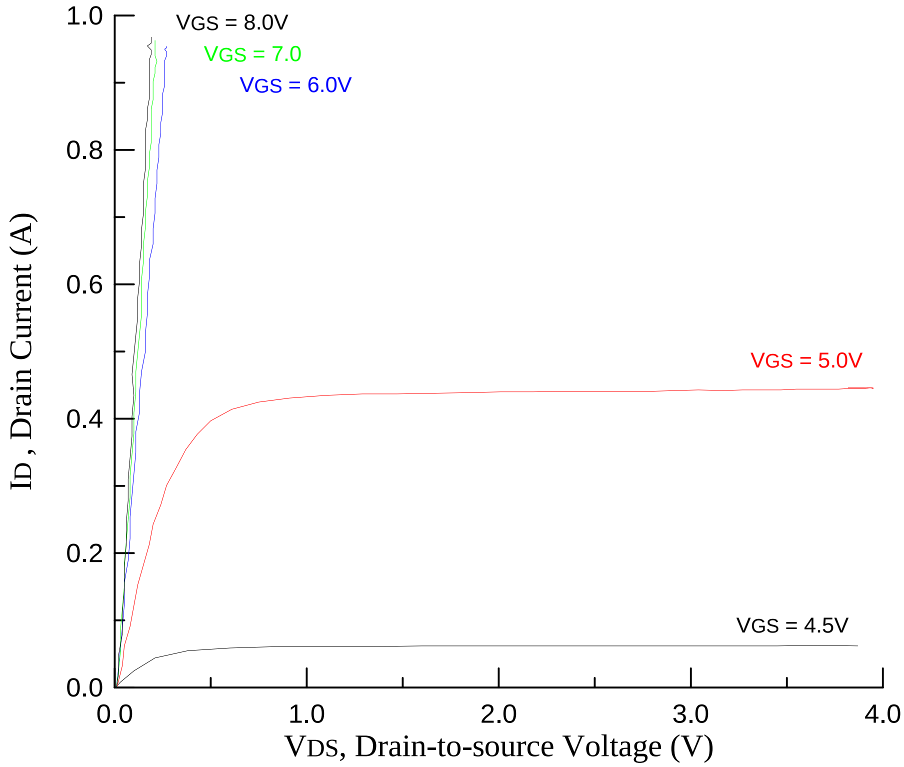


Figure 4. Output characteristics of the IRFD110 device at -190 °C.

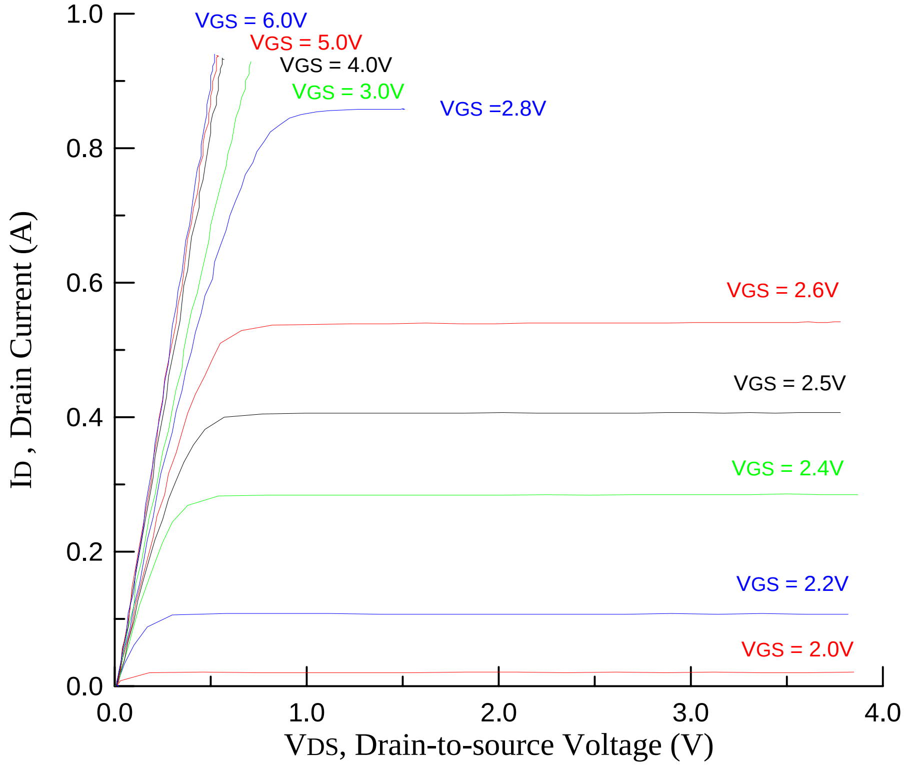


Figure 5. Output characteristics of the HTANFET device at 20 °C.

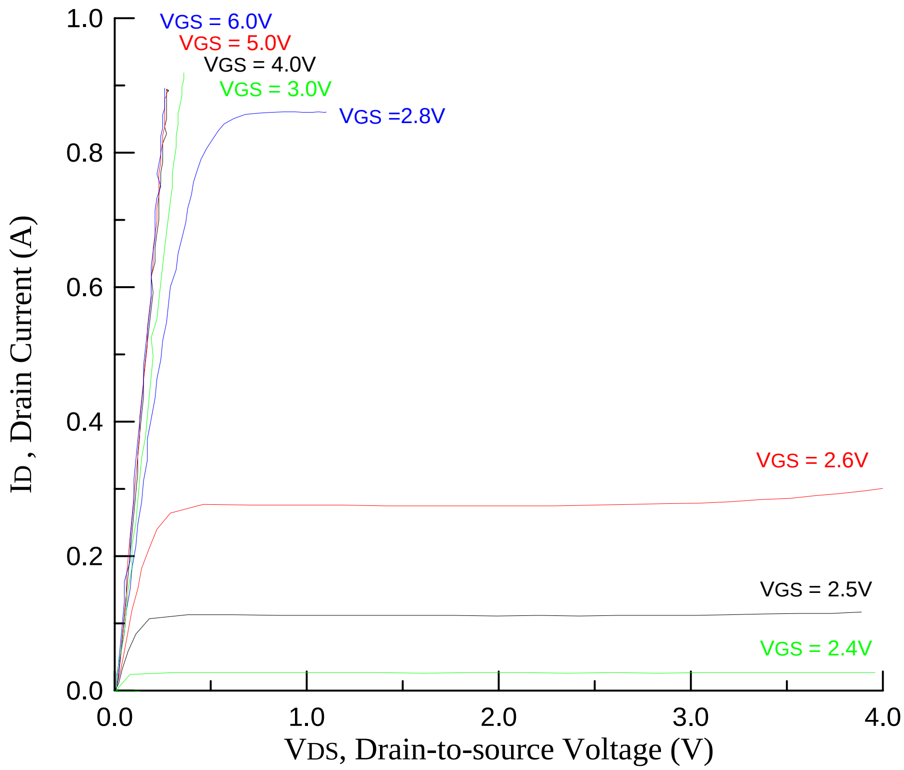


Figure 6. Output characteristics of the HTANFET device at -190 °C.

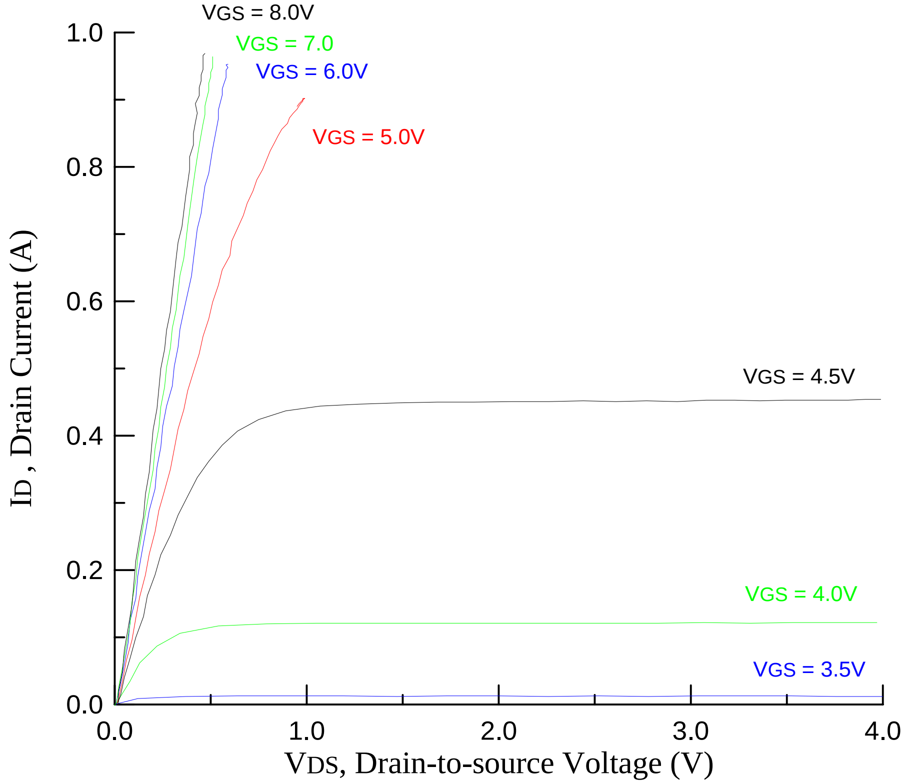


Figure 7. Output characteristics (at 20 °C) of the IRFD110 device before thermal cycling.

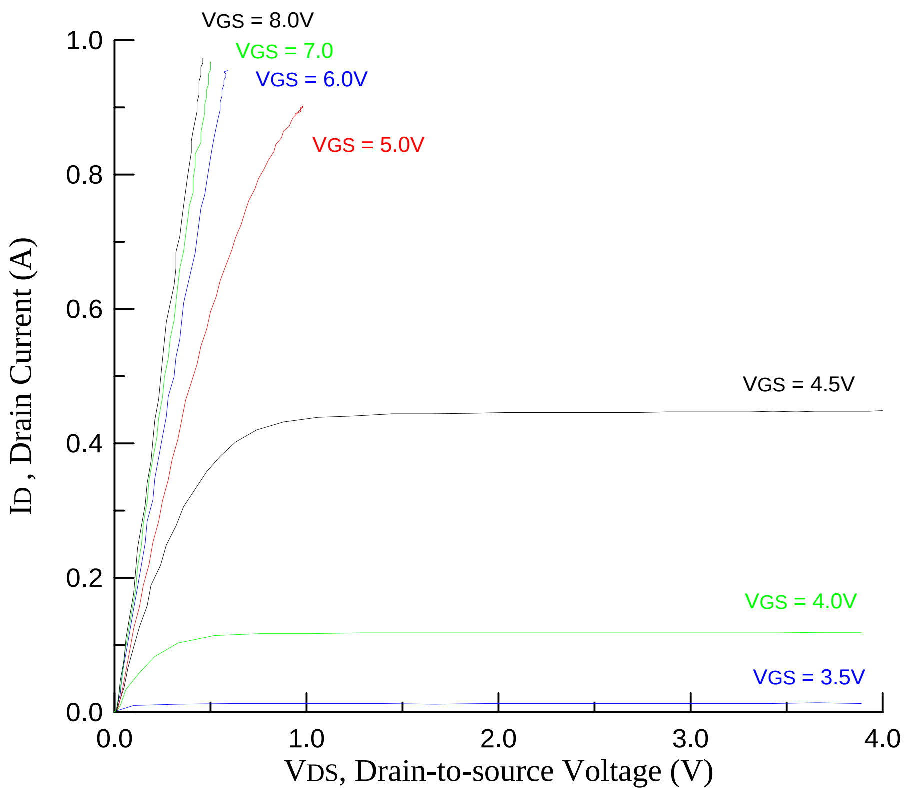


Figure 8. Output characteristics (at 20 °C) of the IRFD110 device after five thermal cycles.

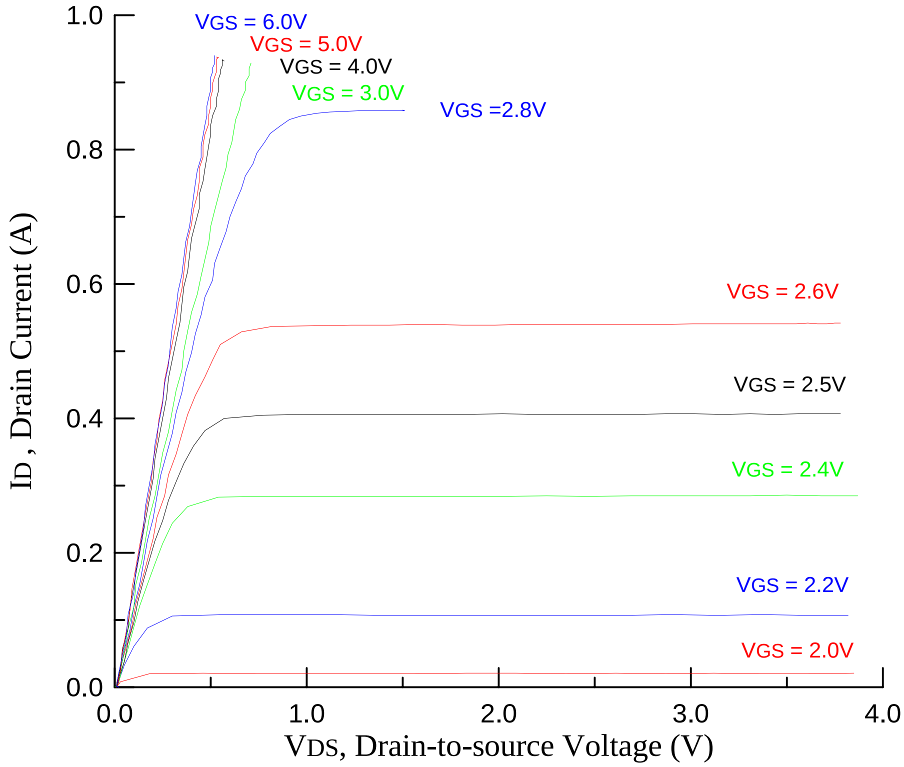


Figure 9. Output characteristics (at 20 °C) of the HTANFET device before thermal cycling.

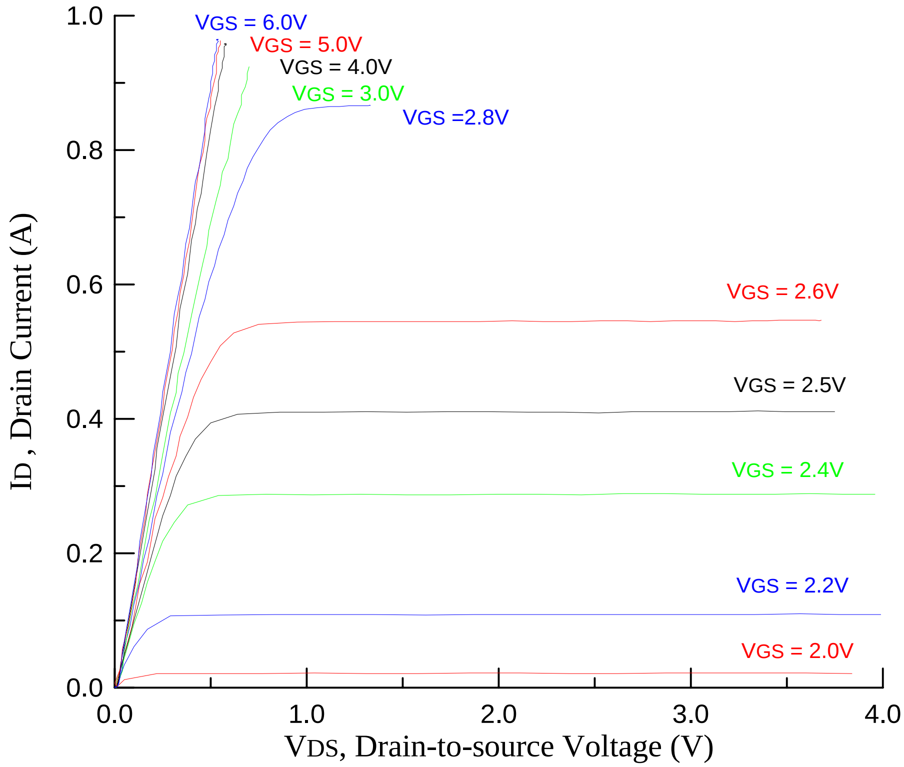


Figure 10. Output characteristics (at 20 °C) of the HTANFET device after five thermal cycles.

Table II. Effects of thermal cycling on gate threshold voltage ($V_{GS(th)}$) and on-state resistance ($R_{DS(on)}$).

	$V_{GS(th)}$ (V)		$R_{DS(on)}$ (Ω)	
Device	Before (20 °C)	After 5 cycles (20 °C)	Before (20 °C)	After 5 cycles (20 °C)
IRFD110	3.03	3.04	0.49	0.48
HTANFET	1.64	1.65	0.58	0.59